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Identification of Success Criteria for Automated Function Using Feed and Bleed Operation

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1. Introduction

Various safety systems have been placed in nuclear power plant (NPP) to protect integrity of reactor vessel and prevent radioactivity release when an accident occurs. However, since NPP has lots of functions and systems, operated procedure is much complicated and the chance of human error to operate the safety systems is quite high [1]. In the case of large break loss of coolant accident (LBLOCA) and station black out (SBO), the dependency of operator is very low. However, when many mitigation systems are still available, operators have several choices to mitigate the accident and the human error can be increased more. To reduce the operator's workload and perform the operation accurate after the accident, automated function for safe cooldown based on the feed and bleed (F&B) operation was suggested [2]. The automated function can predict whether the plant will be safe after the automated function is initiated, and perform the safety functions automatically. To expect the success of cooldown, success criteria should be identified.

2. Sequence of RCS situation when heat removal by secondary system fails

The F&B operation is the process of primary cooling system and it is important because it is last resort if all other attempts failed. In conventional emergency operation procedure, the F&B operation can start, if secondary system is failed to remove heat from the primary coolant [2]. To identify the success criteria, sequence of RCS (reactor coolant system) situation when heat removal by secondary system fails should be identified.

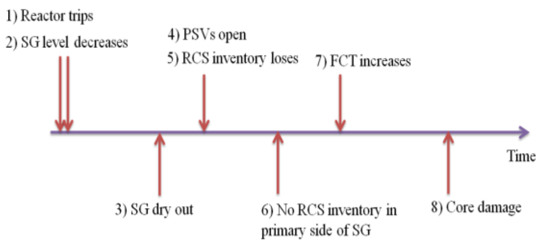

Fig. 1. Sequence of RCS situation without F&B operation when heat removal by secondary system fails (Non-LOCA)

The reactor will trip when the abnormal event occurs. In view point of heat removal, abnormal events can be classified as non-LOCA and LOCA [3].

If the non-LOCA with failure of heat removal by secondary system occurs, the RCS situation changes as shown in figure 1.

If the SG (steam generator) loses the capacity of heat removal because of any reasons, the SG level will decrease. According to the start time of decrease of SG level, the loss of heat removal by SG will be changed. Since SG level decreases, an amount of heat removal though the SG decreases. Eventually, heat cannot be removed by SG when the SG dries out. Because the RCS loses all heat mechanism, the coolant becomes saturated, and then RCS pressure increases.

To prevent the integrity of RCS vessel, the PSVs (pressurizer safety valves) open automatically. PSVs open and close according to the RCS pressure repeatedly. Since PSVs open, the inventory of RCS coolant loses. As time goes by, the RCS coolant loses a lot, and then the upper part of RCS becomes uncovered. Even though the SG recovers the capacity to remove the heat of primary system, the SG cannot remove the heat because there is no flow rate in U tube.

The FCT (fuel cladding temperature) increases because the inventory of coolant loses and coolant becomes superheated. When the FCT rises up to 1000 K, a fuel cladding oxidation begins. Following this time, FCT rises abruptly due to heat generation associated with fuel cladding oxidation [3]. Fuel cladding oxidation occurs largely when the fuel cladding temperature rises over the 1200 K. Eventually, the core will be damaged. Core damage is assumed for sequences with a PCT (peak cladding temperature) above 1477K [4].

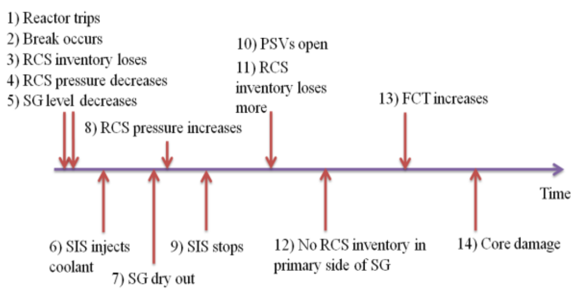

Fig. 2. Sequence of RCS situation without F&B operation when heat removal by secondary system fails (LOCA)

If the LOCA with failure of heat removal by secondary system occurs, the RCS situation changes as shown in figure 2.

Because the break occurs, the SI can inject the cold coolant to RCS. Since the break is small and heat removal by SG is insufficient, the pressure increases. Then, the SI (safety injection) cannot inject the coolant. Differences between the small break LOCA and Non-LOCA are the amount of loss of coolant inventory, and time of step 10 to 14.

3. Identification of successful cooldown of F&B operation

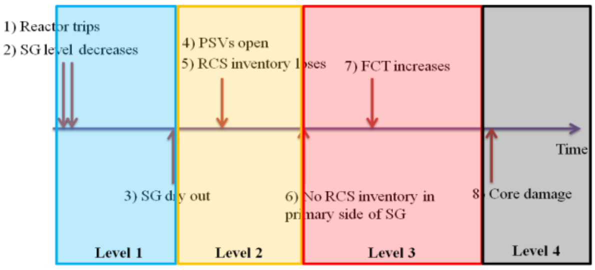

Fig. 3. Level of automated function to expect the necessity of F&B operation (Non-LOCA)

Objective of the automated function is to make the RCS condition reach the shutdown cooling system (SCS) entry condition (28.27bar, 176.7C) without core damage by using the F&B operation. To identify the success criteria, automated function has four levels according to the necessity of F&B operation.

If the non-LOCA with failure of heat removal by secondary system occurs, the levels of automated function are shown in figure 3.

Level 1 is from step 1 to step 3. Reactor has heat removal mechanism until the SG dry out. In the Level 1, the automated function observes the SG level.

Level 2 is from step 3 to 6. When the PSVs open, RCS inventory loses and inventory cannot be recovered. Until the loss of inventory in U-tube, heat can be removed by SG when the SG is recovered the ability of heat removal. In the Level 2, the automated function observes water inventory, pressure, flow rate in U-tube, water level in U-tube, and PSV status.

Level 3 is from step 6 to deadline of F&B operation which is avoidable limitation of core damage. After the dry out in U-tube, the F&B operation is the only way to prevent the core damage. Even though SG is recovered the ability of heat removal, the heat removal is not possible during the Level 3. Until deadline of F&B operation, the F&B operation should be initiated. According to the component status of F&B operation such as availability SDS (safety depressurization system) valves and SI pumps, the FCT can increase after the F&B operation is initiated because the opened area of SDS valves affects decrease of RCS pressure, and flow rate of SI is related to RCS pressure and the availability of SI components. During the Level 3, the automated function observes opening area of SDS valves, flow rate from SI, RCS pressure, and RCS temperature.

Even though the F&B operation is initiated, core will be damaged or already damaged during the Level 4. The case that the components of F&B operations break all down is comprised in Level 4.

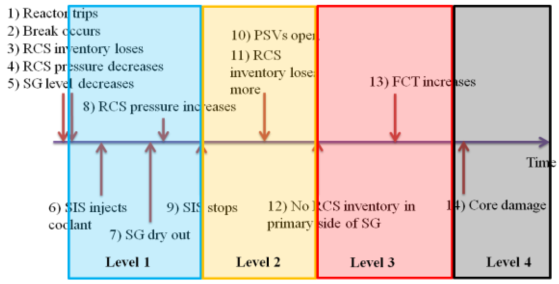

Fig. 4. Level of automated function to expect the necessity of F&B operation (LOCA)

If the LOCA with failure of heat removal by secondary system occurs, the levels of automated function are shown in figure 4.

According to the break size, the flow rate from SI will be decided because the break size affects the RCS pressure. If the break size is too small, RCS pressure decreases a little. Then, the flow rate from SI is not enough to cool down the reactor without SG. Pressure increases and SG dries out. In the Level 1, the automated function observes SG level, pressure, and SI flow rate. Level 2, 3, and 4 are as same as Non-LOCA case.

3. Conclusions

To perform the operation accurately after the accident, the automated function for safe cooldown based on the F&B operation is suggested. To expect the success of cooldown, sequence of RCS situation when heat removal by secondary system fails is identified. Based on the sequence of RCS situation, four levels of necessity of F&B operation are classified. To obtain the boundary of levels, the TH analysis will be performed.

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